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CONTROL OF THE MAIN-RING MAGNET POWER SUPPLIES

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For the bending magnet system, there will be 24 power supplies approximately equally spaced around the ring. The quadrupole system is similar, with 12 supplies. The power supplies are nominally in series. However, the unavoidable stray capacity to ground causes the ring to be electrically equivalent to a delay line, with a total transit time of about 15 milliseconds. It is clear that any locally applied current regulation of the power supplies will have a very small loop gain-bandwidth product. Further, although the distribution of the emf around the ring can ideally limit the peak voltage to ground to half the output of one supply, improper control could increase this by a factor of 12, and in extreme cases, by more than a factor of 20.

The power supplies will operate directly from the power line with no flywheel energy storage. The reasons for this are economy and reliability. This does, however, add complications to the control system as the energy storage in a typical power supply for a proton synchrotron serves as a filter to eliminate the effects of the more rapid power line fluctuations, the most elementary controls being able to take care of the slow power line fluctuations and thermal drifts. There does remain, however, the problem of establishment of the correct current-time relationship in such a system.

In our system, the problem of providing regulation, i.e. eliminating unwanted fluctuations, is best viewed as a battle against what might be termed noise sources. The higher the characteristic frequency of the noise source, the more important it is to take care of it as close to the source as possible. For this reason, each of the individual 24 power supplies will be locally voltage regulated. The advantage of this technique is that it eliminates most of the complication caused by the complex nature (similarity to a delay line) of the load from the regulation loop which takes care of rapid fluctuations. Each power supply, then, must have locally stored the voltage program which will result in the correct current program. The generation of this voltage program becomes the main function of the overall power supply control system. The actual voltage regulation will not be difficult as computer studies of the planned method of generating the firing pulses for the thyristors indicate that the output of the supply will not depend on the input line voltage to a good approximation.

The system which generates the voltage programs for the 24 power supplies has requirements other than the required magnet current program. Thyristor power supplies operated "phasedback" so that they produce less than their maximum output, draw a large amount of inductive current from the power lines. The worst case occurs when the output is 0.707 of the maximum output at which time the inductive component of the current is half the full load current. If all 24 supplies are simultaneously passed through this condition, this would produce intolerable power line voltage fluctuations. An improvement of about a factor of two is achieved by operating each supply either almost fully on (phased back only enough to allow voltage regulation) or bypassed. The supplies are thus turned on one at a time. There is a brief period during which each supply passes through the worst case condition, but this does not contribute appreciably to the inductive current drawn by the system. We see that the power supply control system not only must generate the required overall voltage program, but must divide this program into 24 pieces, each one for one supply in such a way as to minimize the inductive current. A further requirement is that this division must be such that the peak voltage to ground is kept to a minimum.

With the higher frequency power line "noise" eliminated from the system, the only servo function of the voltage program generator is to eliminate slow (e.g. thermal) drifts. This need not be done rapidly--an average over a large number of pulses can provide the control. This thought leads to the use of the concept called "self-correcting function generator." In this case, it would function as follows. The desired magnet current program would be stored in the form of a table of values in a computer. The accuracy required is high so that a 12-bit computer would need to operate double precision. From the known approximate values of the total (for the ring) inductance and resistance, a provisional voltage program is computed. This allows the power supply system to be placed into operation. A precision (second harmonic type) magnetic current tranducer monitors the actual magnet current achieved. The output of the current monitor is digitized and the data is transmitted to the computer. For additional precision, and for checking for spurious effects, the current should actually be monitored at several (two to four) points. The computer compares the actual current program with the desired one and from the difference the voltage program error is computed using the known inductance and resistance. A fraction less than unity (for stability) of this is then applied as a correction to the stored voltage program. The voltage program will converge rapidly to the correct one and the computer can easily divide this among the 24 power supplies. The voltage program for an individual power supply can be exceedingly simple. Needed are the turn-on time, the rate of voltage rise (the rise lasts about 60 milliseconds), the forward (rectify) voltage, the time of start of invert, the reverse (invert) voltage, and the turn-off time. No corrections should be needed during the injection or flat-top periods, unless a slope is desired on flat-top.

The quadrupole system can be exactly the same in concept except that the requirements on ripple are more stringent. There is always present high-frequency ripple generated by the commutation between thyristors. A dynamicripple filter can easily cope with this component. (Studies of extraction indicate that the high-frequency ripple would cause little trouble, anyway.) The troublesome ripple is low-frequency ripple generated by phase-to-phase power line unbalance and by errors in the thyristor firing circuits. The "self-correcting function generator" concept can be used to eliminate this problem. It could be described as a "self-adjusting hum bucker."

The components of a given ripple frequency, in phase with and in quadrature with a reference signal of the same frequency can be measured during the period when the supply is supposed to generate a constant voltage, or better, when the magnet current is supposed to be constant. These numbers can be summed into a register which sets the value of a compensating ripple applied to the voltage reference of the firing circuits. The phase relation between a ripple component applied to the firing circuit reference and the output ripple voltage must be empirically determined and allowed for in the controlling computer. This concept is sufficiently simple that we believe it should be applied to the bending-magnet power supplies too. The advantage is that the firing curcuits would require less precision in their manufacture. The dynamic ripple filter would not be needed on the bending-magnet supplies.